High Q R&D at FNAL: a newly discovered surface treatment to triple SRF cavity efficiency

Anna Grassellino

SRF development department, FNAL

All Experimenters Meeting

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U.S. DEPARTMENT OF ENERGY

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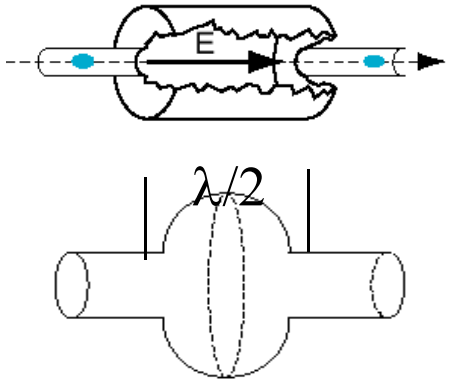
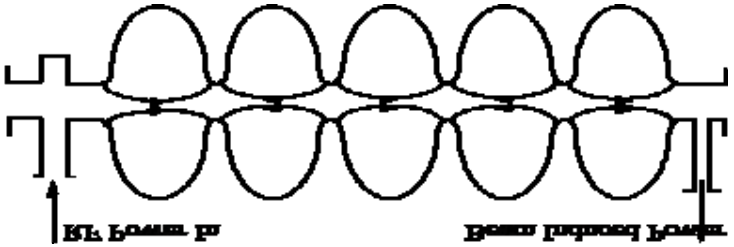
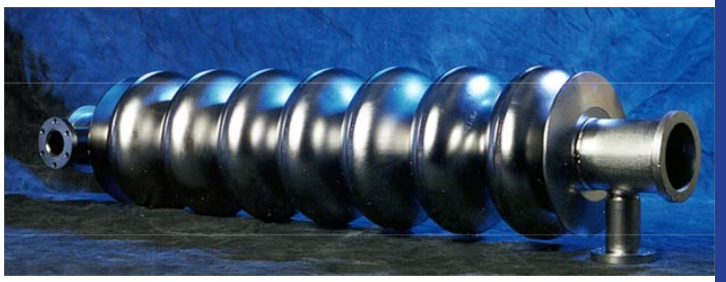
Superconducting RF cavities

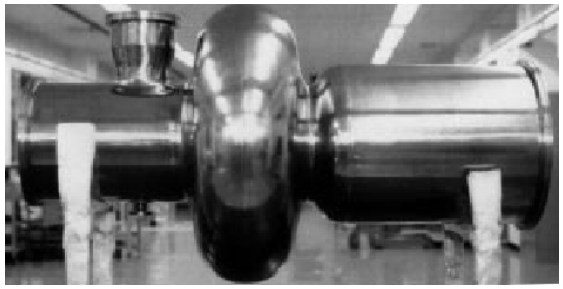


Basic Principle, v/c = 1

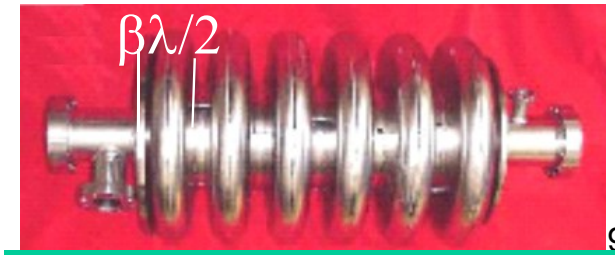




Multi-Cell Cavity



Single Cell



Squeezed Cells for v/c = 0.5

Q curve: past and present

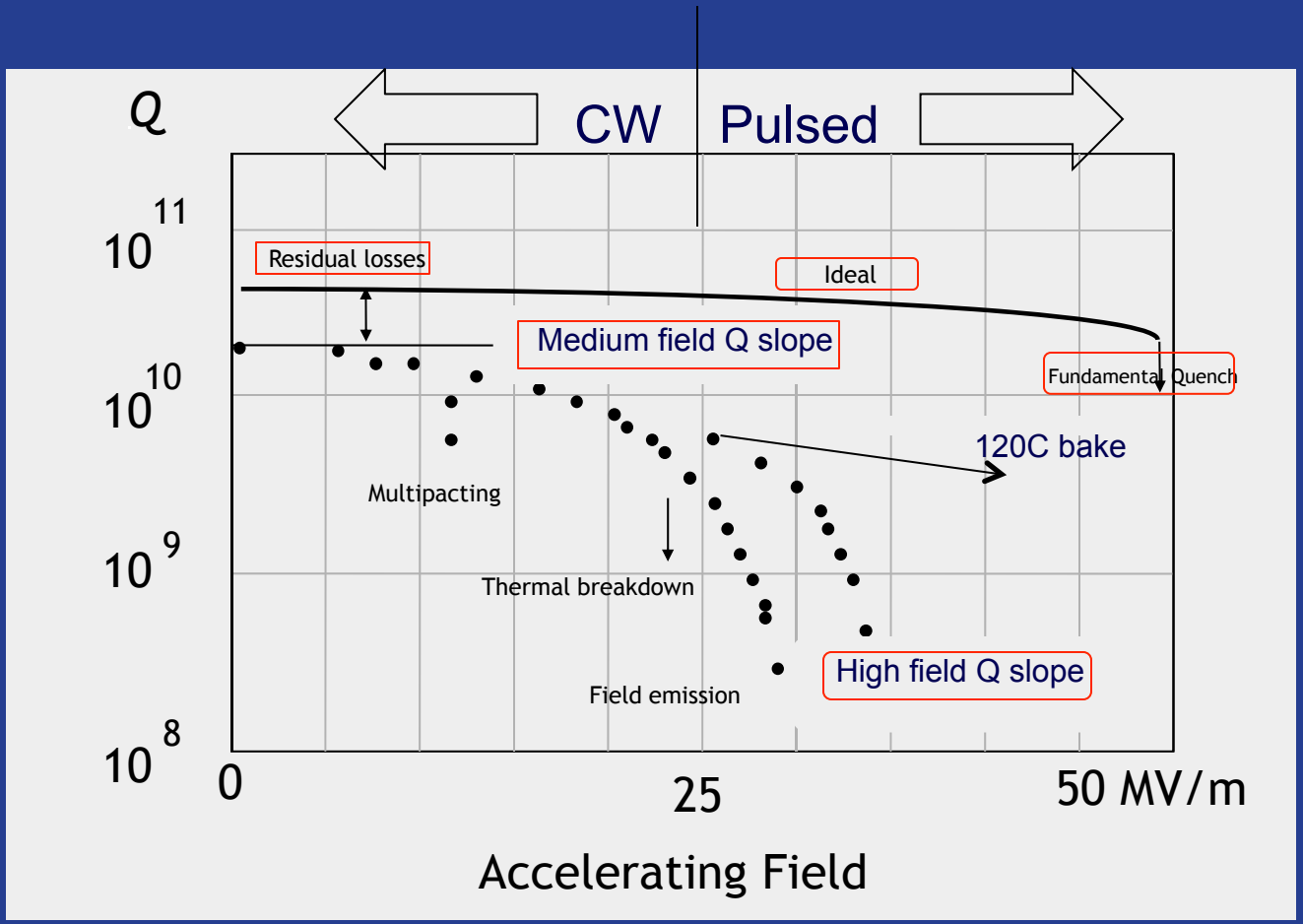
Among main factors of merit:

- Quality factor of the resonator
- Achievable gradients

$$Q_0 = \frac{\omega_0 \mu_0 \int_V |\mathbf{H}|^2 \, dv}{R_s \int_S |\mathbf{H}|^2 \, ds}.$$

$$Q_0 = \frac{G}{R_s},$$

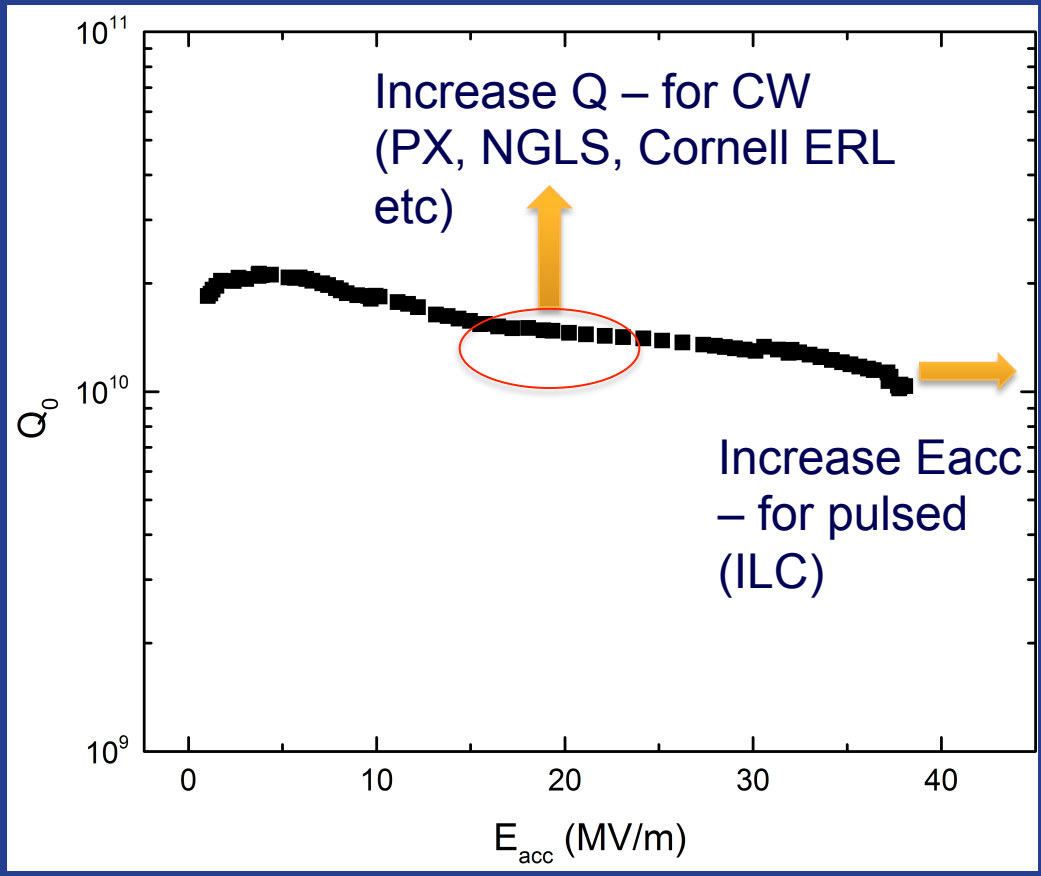
$$G = \frac{\omega_0 \mu_0 \int_V |\mathbf{H}|^2 \, dv}{\int_S |\mathbf{H}|^2 \, ds}$$



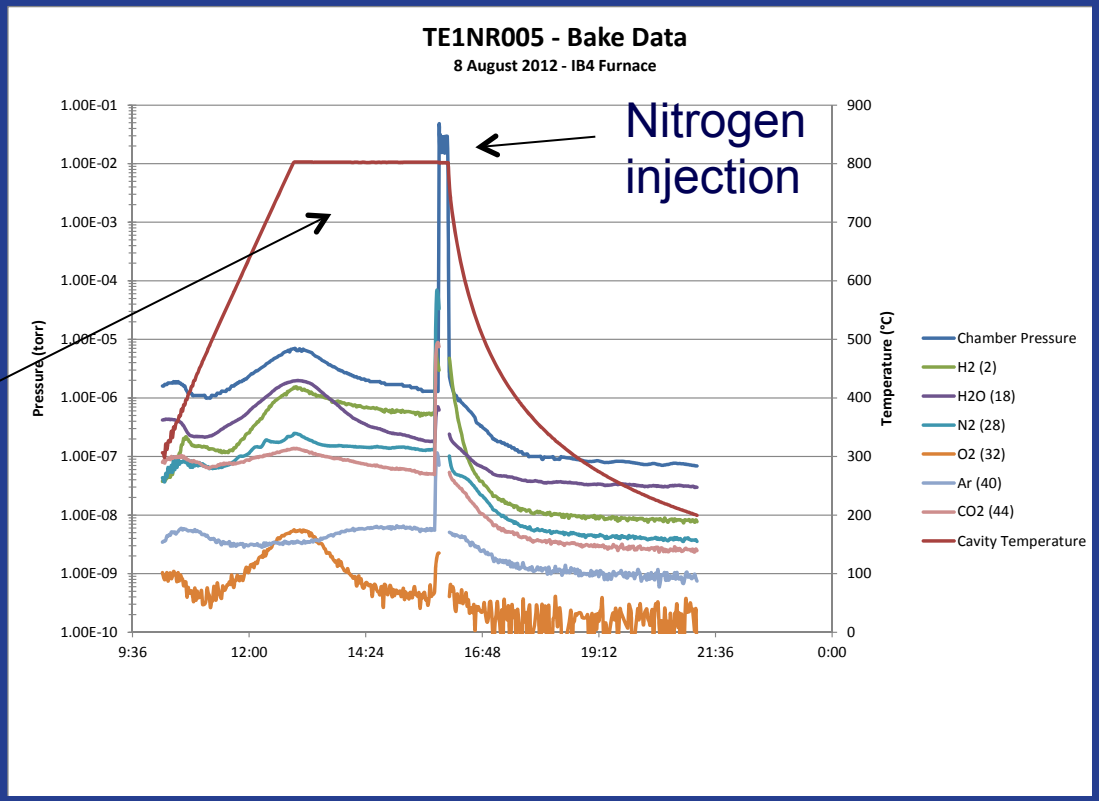
Steady progress due to basic understanding of limiting phenomena and invention of effective cures

Need for higher Q

- Increasing Q of cavities – very important for high duty factor accelerators – virtually all planned superconducting machines (e.g. Project X, NGLS, ERLs, XFEL, ADS etc.)
- Capital and operational costs scale with dissipated power ~ 1/Q



New surface treatments for high Q: nitrogen doping



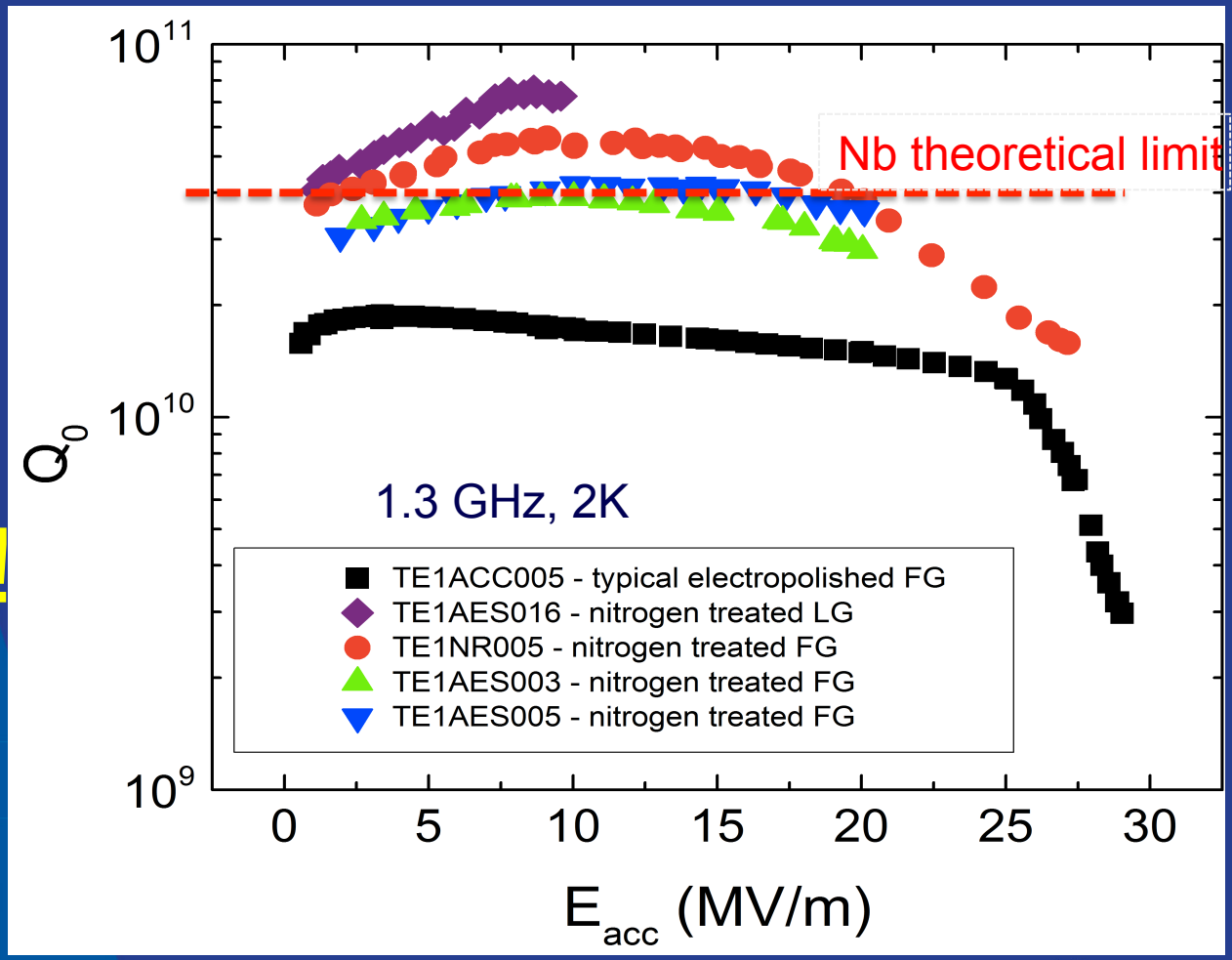
- 4 cavities treated in UHV high T furnace, with injection of small partial pressure of nitrogen
- T range 800-1000C for different duration, followed by different amount of material removal via electropolishing

A.Grassellino et al,
http://arxiv.org/abs/1306.0288

Nitrogen heat treatments

All treated cavities doubled or tripled their efficiency:

World record Q values!



Anti Q-slope!

Efficiency gain up to factor of 3!

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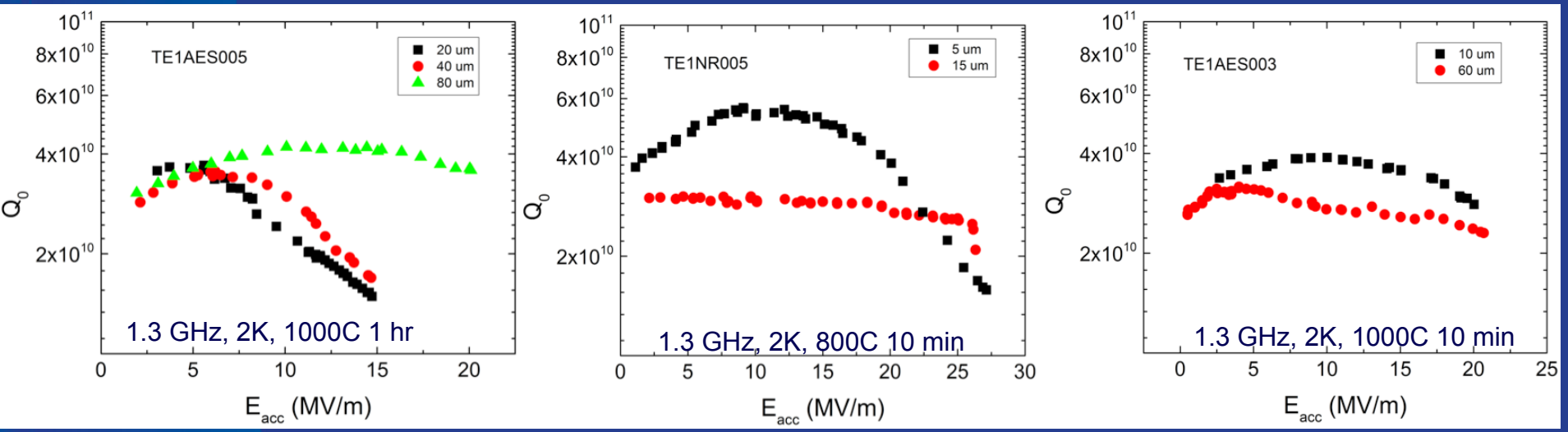
Nitrogen heat treatments

Q curves as a function of material removal via EP post-nitrogen treatment:



- Critical T measured for one cavity ~ 9.2K (standard Nb)
- Studies as function of material removal post nitrogen treatment indicate ideal nitrogen to niobium concentration ratio which gives the anti-slope
- XPS and Auger studies ongoing to determine this ideal concentration

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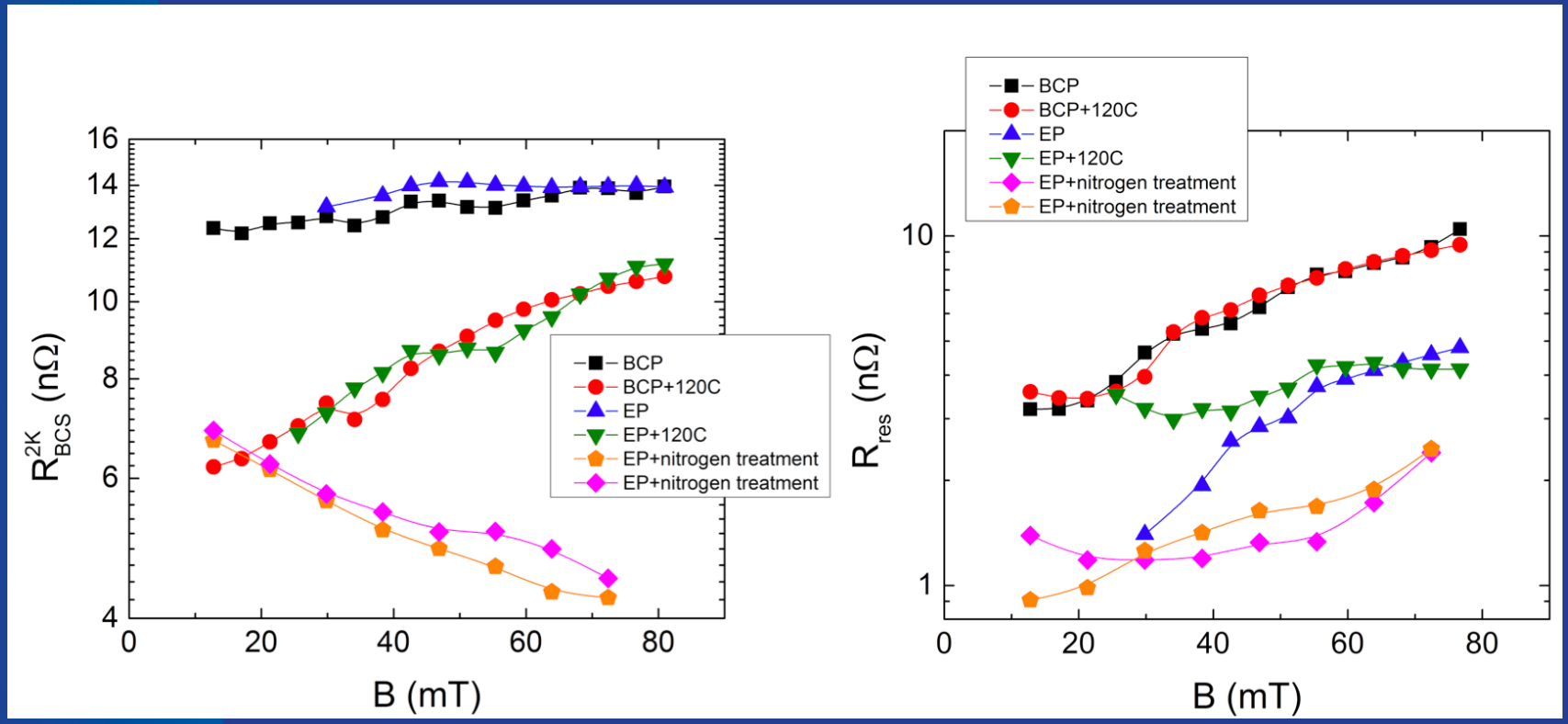
Nitrogen heat treatments

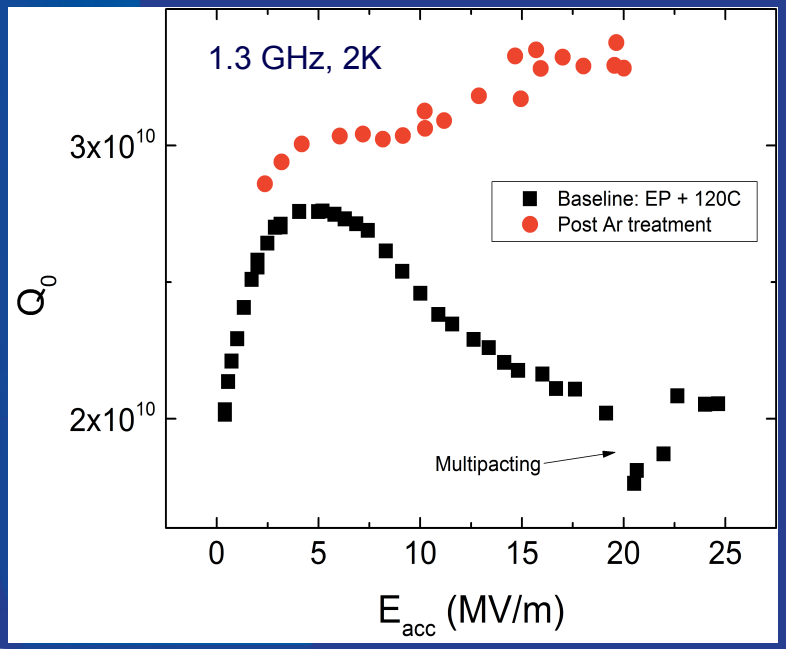


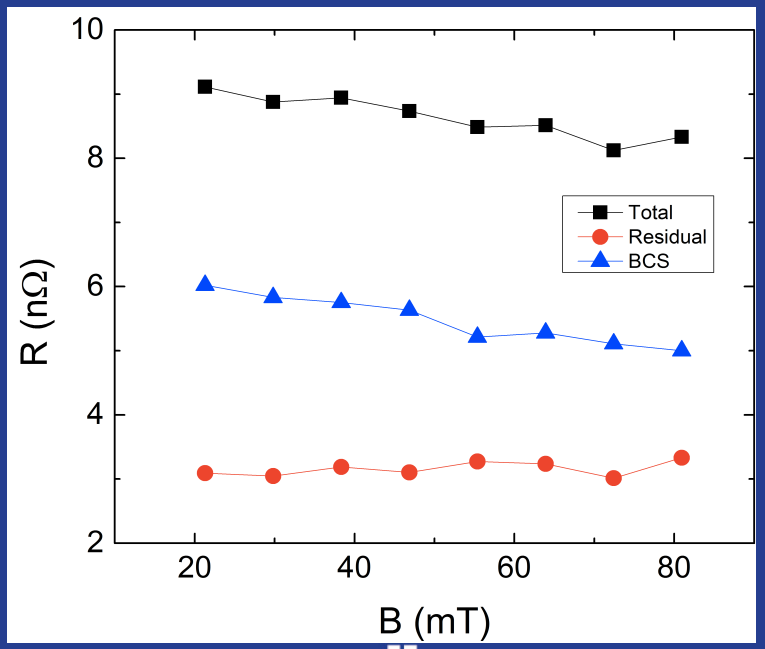
Deconvolution into the BCS and residual resistance reveals a decreasing with field T dependent component! Will try also on 3.9 GHz cavities

Doping with interstitial impurities: a solution for MFQS?

The cavity baked with argon

- Cavity baked at 800C for an hour in UHV, followed by an hour at 800C in partial pressure ~2×10^{-2} T of Argon → *Q ~1×10^{7}*
- Then ~ 7 micron removal via EP → *again anti-Qslope!*
- *IMPLICATION: we have found the cure for the medium field Q-slope!*





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Conclusions

- Just little over a year of high Q R&D has already produced breakthrough results
- The results represent a milestone for the SRF technology
- Results have triggered new R&D directions at other institutions, experimental and theoretical groups
- High Q R&D program ongoing exploring other ideas and optimizing the recipe found
- International High Q collaboration established (Cornell, DESY, Berkeley, Jlab, TRIUMF, HZB, KEK, IHEP…) with Fermilab playing a leading role